

AVHRR IMAGERY AND THE NEAR REAL-TIME CONSERVATION OF ENDANGERED SEA TURTLES IN THE WESTERN NORTH ATLANTIC

by

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Abstract

Surface seawater temperature imagery from the Advanced Very High Resolution Radiometry (AVHRR) sensor of the U.S.A.'s NOAA-11 polar orbiting satellite is being used to reduce the impact of commercial trawl fishing on populations of threatened and endangered sea turtles off the east coast of the U.S.A. During late autumn and early winter, southerly migrating summer flounder (*Paralichthys dentatus*) and sea turtles co-occur on the narrow continental shelf in the vicinity of Cape Hatteras, North Carolina. All five sea turtle species found in this area are protected under the Endangered Species Act (PL93-205); four of the five are known to be captured and drowned in flounder trawl nets. Superimposition of sea turtle positions (from aerial surveys and at-sea observers) on AVHRR imagery demonstrated that risks to sea turtles are greatest when water temperatures are 11°C or greater. Seawater temperatures in this area, documented by AVHRR imagery, are highly influenced by the position and activity of the Gulf Stream, both of which are unpredictable on time scales necessary for the management of sea turtle/fishery interactions. During the past three fishing seasons, turtle conservation measures, such as tow time restrictions and turtle excluder devices, have been imposed on the fishery. AVHRR imagery is being used to evaluate and modify, in near real-time, the duration and geographic extent of existing regulations, so that sea turtles receive adequate protection and the fishery, with reasonable restrictions, can continue to operate.

INTRODUCTION

Environmental information collected by satellite-borne sensors has only recently been applied to the management of living marine resources. Within the past five years, near real-time, remotely-sensed data, available through NOAA's Coastal Ocean Program CoastWatch project, have been used to support a number of management activities (Celone and Smith, 1992). Examples include an assessment of the origin and persistence of a toxic red tide off the Atlantic coast of the U.S.A. (Tester et al., 1991), initialization and evaluation of a system to forecast environmental conditions in the North American Great Lakes (Leshkevich et al., 1993), and development of El Nino Watch, a monthly synopsis of ocean conditions and potential impacts on fishery stocks off the Pacific coast of the U.S.A. The purpose of the present paper is to review the use of near real-time, AVHRR-derived, sea surface temperature imagery in the management of a fishery whose operation has been documented to take threatened and endangered sea turtles (Anonymous, 1992; Epperly et al., in press).

Five species of threatened or endangered sea turtles are found off the east coast of the U.S.A.: loggerhead (*Caretta caretta*), green (*Chelonia mydas*), Kemp's ridley (*Lepidochelys kempi*), hawksbill (*Eretmochelys imbricata*), and leatherback (*Dermochelys coriacea*). Sea turtles undertake an annual southerly migration each autumn-winter (Shoop and Kenney, 1992), which takes them through an area of intensive fishing activity off southern Virginia and North Carolina. Historically, relatively large numbers of turtles have washed ashore dead on the beaches of northern North Carolina during the late autumn and early winter. Major stranding events occurred in 1982, 1990, and 1992 (Crouse, 1985; Epperly et al., submitted-b).

These mortalities have been coincident with a trawl fishery for summer flounder, *Paralichthys dentatus*, active off the coast of southern Virginia and North Carolina during the months of October-April (Magnuson et al., 1990; Anonymous, 1992). Turtles caught in trawl nets drown after a period of forced submergence.

In 1990, 51 turtles, including eight of the critically endangered Kemp's ridleys, washed ashore in the vicinity of Cape Hatteras during the first week of December (Anonymous, 1992; Teas, 1992). High resolution sea surface temperature (SST) imagery indicated a strong intrusion of Gulf Stream water immediately south of Cape Hatteras (Anonymous, 1992). The State of North Carolina closed the territorial sea (0-5.6 km from shore) to flounder trawling on December 7, and reopened it on December 26 to vessels using Turtle Excluder Devices (TEDs) (N.C. Division of Marine Fisheries, 1991; Anonymous, 1992).

In preparation for the 1991-1992 fishing season, the U.S. National Marine Fisheries Service (NMFS) and the North Carolina Division of Marine Fisheries developed a cooperative plan to monitor the fishery and protect sea turtles (Epperly et al., in press). The plan included an at-sea observer program, aerial surveys for fleet location and the presence of turtles, and examination of SST imagery. In addition, the Federal and state agencies imposed a tow time limit of 60 minutes bottom time on trawlers operating south of Cape Charles, Virginia.

In this paper, we review the results of the 1991-1992 monitoring efforts. In particular, we emphasize the contribution of SST imagery to an understanding of ocean/climate factors affecting sea turtle distributions and the likelihood of interactions with the flounder fishing fleet. We then demonstrate how this knowledge was used in combination with near real-time SST imagery to manage sea turtle/flounder trawler interactions during the 1992-1993 season.

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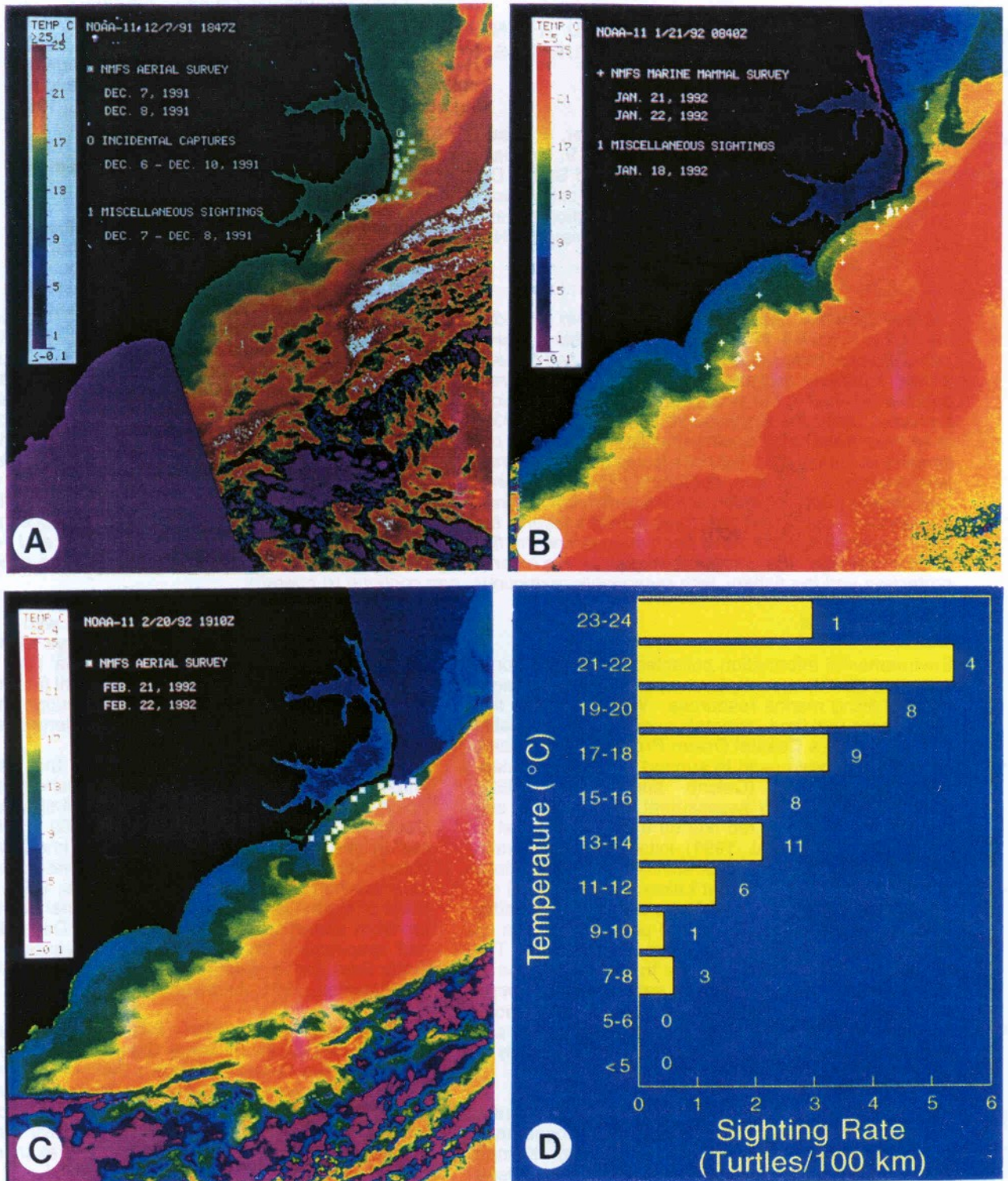


FIGURE 1. Sea turtle sightings from aerial surveys superimposed on sea surface temperature imagery from the AVHRR sensor aboard the NOAA-11 polar orbiting satellite. White areas represent water temperatures $> 25.3^{\circ}\text{C}$. Magenta denotes cloud cover or areas outside the sensor path. A) December 7, 1991; B) January 21, 1992; C) February 20, 1992; D) histogram of aerial survey sighting rates for sea turtles at various temperature ranges; numerals to the right of histogram bars are actual numbers of sea turtles seen.

METHODS

Federal and state observers were placed aboard flounder trawlers to observe and monitor captures and mortalities of sea turtles during the 1991-1992 season (Epperly et al., in press). The program initially was voluntary on the part of vessel captains, but when sufficient fleet coverage was not obtained, it was made mandatory by the Federal Government. Observers monitored the location, depth, sea surface temperature, and duration of each tow, and documented all incidental captures of sea turtles. Sea turtles were identified, measured, tagged, and released. Resuscitation of comatose turtles was attempted. Dead turtles were returned to shore for necropsy. Stratified random survey techniques were used to estimate total captures and mortalities of sea turtles (Epperly et al., in press).

Aerial surveys for sea turtles followed methodology similar to that established for inshore waters of North Carolina (Epperly et al., submitted-a). Surveys were conducted from 0-28 km from shore at an altitude of 152 meters and an air speed of 185-222 km/hr. The coastal area north of Cape Lookout was divided into five zones; approximately 10% of a zone could be visually surveyed during a flight. The number and density of turtles on the surface of a zone was estimated with strip and line transect methodology (Epperly et al., in press).

SST imagery from the AVHRR sensor on the NOAA-11 polar orbiting satellite were obtained daily in near real-time (6-12 hours after satellite passage) from the NOAA Coastal Ocean Program's CoastWatch project (Chester and Wolfe, 1990; Leshkevich et al., 1993). Each image consisted of 512 X 512 pixels, with a resolution of approximately 1.2 km. Hourly wind observations at Cape Hatteras were provided by the U.S. National Weather Service. Positions of sea turtles were superimposed on SST imagery to examine patterns of distribution with respect to oceanographic features. Where same-day imagery was cloud-free, SSTs under each survey transect were extracted digitally, and sighting rates (turtles/100 km) were estimated for each 2-degree temperature interval.

RESULTS AND DISCUSSION

1991-1992 Season

A. At-Sea Observations

Observers aboard approximately 6% of an estimated total of over 700 fishing trips made between November, 1991 and February, 1992 reported capture of 83 turtles (Epperly et al., in press). Most were loggerheads, but an unexpectedly large proportion (35%) were Kemp's ridleys. Catch rates tended to be greater earlier in the season (November-December), south of Cape Hatteras, in relatively shallow depths (<20 m), and in warmer water (>15°C). Active sea turtles were caught in waters as cold as 10°C. The fleet captured an estimated total of about 1000 turtles of which approximately 100-200 were estimated to have drowned (Epperly et al., in press).

Observer data and overflights indicate that vessels fished together on common fishing grounds; tow time data indicate that only about one-fourth of all tows complied with the legally-required 60 minute bottom-time constraint. A strong relationship exists between

tow time duration and turtle mortalities (Henwood and Stuntz, 1987), and multiple captures of a turtle increase physiological stress (Lutz and Dunbar-Cooper, 1987; Lutcavage and Lutz, 1991; Stabenau et al., 1991). Hence, tow time restrictions are a viable management option only when compliance can be ensured and fishing activity is not aggregated (Magnuson et al., 1990).

B. Aerial Surveys / Sea Surface Temperatures

Aerial survey results (Figure 1, A-D) show that sea turtles occurred over a wide range of SSTs, but were most abundant at warmer temperatures (Figure 1D; Epperly et al., in press). In the winter, the entire area is influenced by the warm, fast moving Gulf Stream and its meanders that impinge upon and override the continental shelf. In the absence of strong northerly winds, warm Gulf Stream water occupies the shelf area between Cape Hatteras and Cape Lookout (Figure 1, A-B). In extreme cases, this influence extends into the nearshore waters north of Cape Hatteras (Churchill and Cornillon, 1991). Waters over the continental shelf are generally warm early in the winter and turtles are found widely distributed throughout the coastal ocean (Figure 1A); later in the winter, coastal waters are cooler, and turtles occur in proximity to well-defined thermal fronts (Figure 1B). Gulf Stream frontal eddies enhance this situation by advecting warm water into the nearshore areas south of Cape Hatteras (Figure 1B). In contrast, strong, sustained northerly winds push cold Virginia Coastal Water southward along the North Carolina coast to Cape Hatteras, flushing warm water out of the area (Pietrafesa et al., in press) (Figure 1C); at times cold water penetrates south of Cape Lookout. Turtles were absent from this cold water and tended to occur along thermal fronts associated with Gulf Stream features (Figure 1C). Sighting rates of sea turtles during aerial surveys varied with sea surface temperatures (Figure 1D). These data indicate 1) sea turtles occur in waters far colder than the ordinarily accepted limit of 15°C (Lutz and Dunbar-Cooper, 1984), and 2) sighting rates decline markedly as water temperatures fall, especially below 11°C.

1992-1993 Season

A. Background

NMFS decided to require TEDs during the 1992-1993 fishery based on low compliance with tow time restrictions and the aggregated fishing patterns observed during the previous year (Epperly et al., in press). TEDs were required on all flounder trawlers operating south of Cape Charles, Virginia. Testing by the North Carolina Division of Marine Fisheries during the summer of 1992 indicated that TEDs could be used successfully to protect sea turtles while retaining flounder. In the fishery, however, especially north of Cape Hatteras, large catches of bycatch species such as sharks and rays sometimes clogged TEDs, causing them to bend or the nets to rip. Fishermen asked NMFS for relief. In particular, they wanted the TED line moved south of Cape Charles on the basis that water temperatures were cold enough to exclude sea turtles. NMFS requested a study of the situation and an assessment of the relative danger to sea turtles under various regulatory scenarios. Because no additional resources were available to support an observer program or to conduct aerial surveys, we relied on data collected in 1991-1992 combined with near real-time

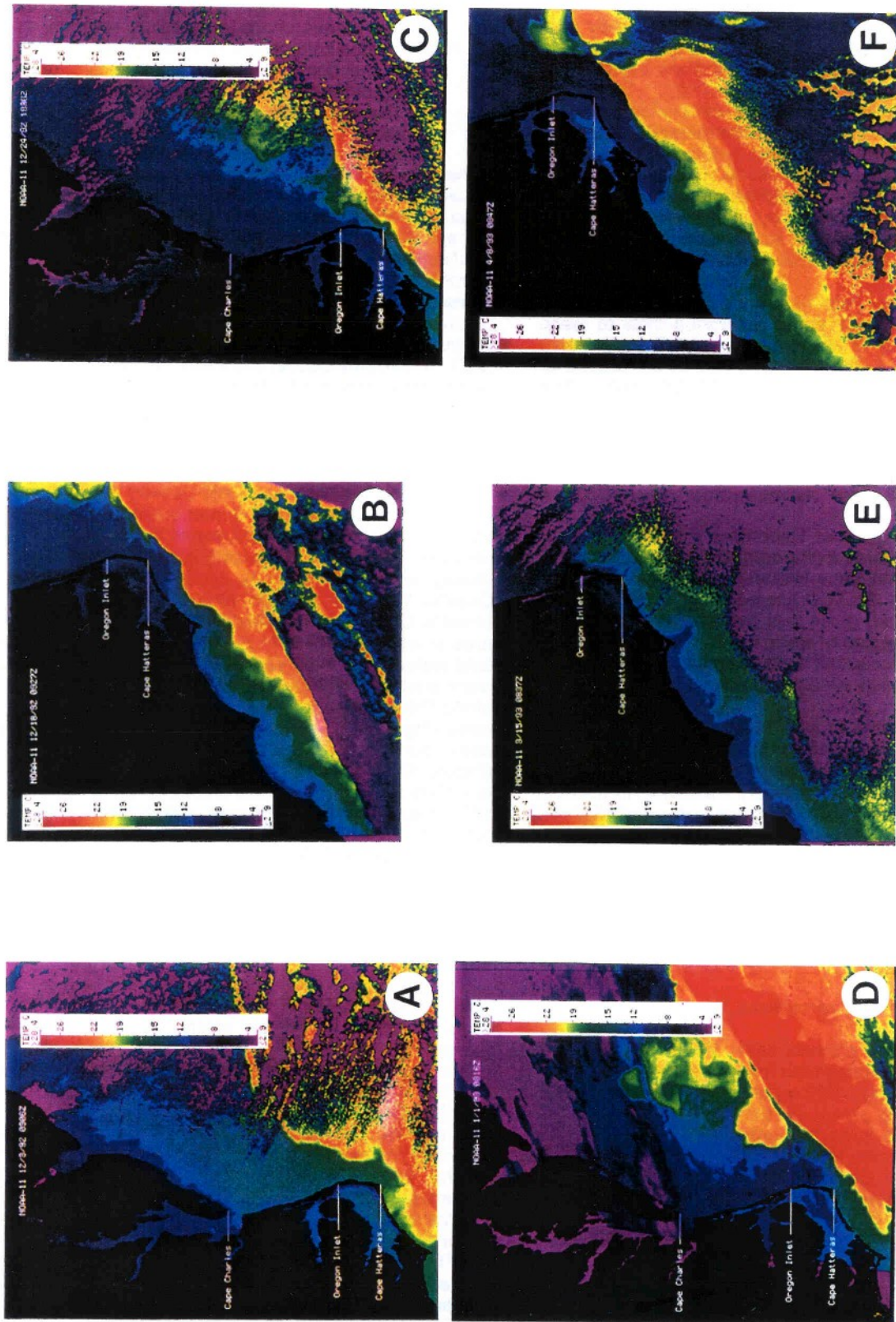


FIGURE 2. Sea surface temperature imagery from the AVHRR sensor aboard the NOAA-11 polar orbiting satellite. Magenta areas indicate cloud cover. A) December 3, 1992; B) December 18, 1992; C) December 24, 1992; D) January 1, 1993; E) March 15, 1993; F) April 8, 1993.

SST imagery during the 1992-1993 season to evaluate risks and formulate recommendations.

B. Risk Assessment

Using data collected in 1991-1992, we assessed the risk to sea turtles of moving the TED line to the south, or eliminating it altogether. Throughout the winter, the Gulf Stream appeared to influence the nearshore waters intermittently as far north as Oregon Inlet, and concomitantly, the distribution of sea turtles. Turtles were caught throughout the fishing season, especially south of Cape Hatteras, but none were captured north of Oregon Inlet after nearshore temperatures dropped below 10°C. Some turtles, however, were caught in waters as cold as 10°C south of Oregon Inlet. In addition, several sea turtles were sighted in waters below 10° during aerial surveys. Thus, moving the TED line south after nearshore waters reach 10°C could not be accomplished without some increased risk to sea turtles. This risk would increase sharply if the line were dropped below Oregon Inlet, and even more so if the line moved to Cape Hatteras or if TED requirements were eliminated entirely, largely because of the uncertainty associated with onshore movements of Gulf Stream water north of Cape Hatteras.

C. Sea Surface Temperatures

During the first week of December (Figure 2A), sea surface temperatures in the nearshore zone between Cape Charles and Cape Hatteras generally exceeded 15°C. Lowering the TED line south of Cape Charles was not advisable, given that the likelihood of turtles was high in the region of warm water. The second and third weeks of December were characterized by strong northerly winds and overcast weather.

The resulting hiatus in SST imagery demonstrates a limitation of the approach for those applications which require reliable daily coverage. The next available cloud-free scene, December 18 (Figure 2B), revealed an intrusion of cold (<10°C) Virginia Coastal Water well south of Cape Hatteras.

On December 24 (Figure 2C), warm Gulf Stream water (>11°C) extended into the nearshore area between Oregon Inlet and Cape Hatteras, but temperatures north of Oregon Inlet remained cold (< 11°C). This event provided convincing evidence of potential risk to turtles if trawlers were permitted to operate without TEDs south of Oregon Inlet.

By January 1 (Figure 2D), the situation had reversed and cold water again occupied the zone north of Cape Hatteras. NMFS lowered the TED line from Cape Charles to Oregon Inlet on January 7, 1993.

With the exception of a few days following a severe storm on March 13 that pushed warm water as far north as Oregon Inlet (southwest winds off North Carolina gusted over 160 km/hr) (Figure 2E), cold water persisted north of Cape Hatteras for the remainder of the fishing season.

The greatest excursion of cold water into the area was found on April 8, when, after a prolonged period of strong northerly winds, cold water extended well south of Cape Lookout and well offshore (Figure 2F). Interestingly, on this date the U.S. Coast Guard reported a massive cold kill of tropical reef fish species southeast of Cape Hatteras.

CONCLUSION

The availability of near real-time SST imagery was essential to NMFS's ability to respond to this endangered species/fishery issue. Knowledge of the Gulf Stream's effect on nearshore temperature regimes, as well as information concerning factors that influence its position over the continental shelf, are critical to an understanding of the distribution of sea turtles off North Carolina. Observer data, aerial surveys, and SST imagery obtained during the previous fishing season together provided the necessary foundation for managing the sea turtle/flounder trawler interaction in 1992-1993. SST imagery facilitated the development of management recommendations and allowed near real-time monitoring of environmental conditions in such a way that sea turtles could be afforded protection and the fishery could continue to operate with reasonable restrictions.

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